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ABSTRACT

This report describes the space position data processing system of the NASA Western Aeronautical Test Range. The system is installed at the Dryden Flight Research Facility of NASA Ames Research Center. This operational radar data system (RADATS) provides simultaneous data processing for multiple data inputs and tracking and antenna pointing outputs while performing real-time monitoring, control, and data enhancement functions. Experience in support of the space shuttle and aeronautical flight research missions is described, as well as the automated calibration and configuration functions of the system.

NOMENCLATURE

ACQ	acquisition (channel)
ADRAN	advanced digital ranging (system)
AFFTC	Air Force Flight Test Center
AFTI	advanced fighter technology integration
AGC	automatic gain control
AOS	acquisition of signal
CPU	central processing unit
DMA	direct memory access (transfer)
E/S	event and status
FTD	formatted radar tracking data (channel)
GPIB	general-purpose instrumentation bus

I/O	input-output (operation or function)
IRIG	Inter-Range Instrumentation Group
LOS	loss of signal
PCA	point of closest approach
RADATS	radar data system
RF	radiofrequency
TACDAC	tactical data acquisition
UHF	ultrahigh frequency
WATR	Western Aeronautical Test Range

INTRODUCTION

A new radar data system (RADATS) is operational on the NASA Western Aeronautical Test Range (WATR) at the Dryden Flight Research Facility of NASA Ames Research Center (Ames-Dryden) in Edwards, California. The highly automated RADATS supports the stringent trajectory measurement demands imposed by the space shuttle program. It also fulfills the complex and varied requirements of the many flight research programs operated from the WATR and provides support for Air Force Flight Test Center (AFFTC) missions when requested. The RADATS development was initiated in 1980, and the system has been operational since 1983.

REQUIREMENTS

The need and requirements for the RADATS were based on experience with aging tactical data acquisition (TACDAC) equipment, the increasingly stringent demands of the space shuttle program, and the requirement to accommodate the Inter-Range Instrumentation Group (IRIG) phase II formats. A need existed for a stand-alone radar data processing system capable of simultaneously processing multiple input and output channels of tracking data while performing numerous real-time monitoring, control, and data enhancement functions. Automated premission and post-mission calibration and the configuration of the radar system, modems, computer, and interfaces were also considerations. The resulting requirements for the system were as follows:

1. Simultaneous encoding and output of three synchronous, real-time formatted, radar tracking data streams, each with unique selectable formats and data contents.
2. Simultaneous receipt, decoding, and parallax correction of two real-time acquisition data streams, each with unique selectable formats and data contents.

3. Automated computer control of the range, azimuth, and elevation designate channels, with capabilities for operator monitoring and selection of the most suitable designate source.
4. Real-time radar data enhancements, including system and propagation path corrections, Kalman filtering, and trajectory designation.
5. Real-time digital recording of any formatted radar tracking data (FTD) or acquisition (ACQ) channel with concurrent offline and postmission playback and analysis capability.
6. Interactive operator control stations providing various radar premission, postmission, and real-time control modes with data and status displays.
7. Flexibility to accommodate changing requirements and increasing demands expected over the next 10 years or more.
8. Simplicity and low relative cost through maximum use of off-the-shelf equipment.

HARDWARE

The RADATS hardware consists of a computer system, an external interface system, a time-code generator-translator, and an external monitoring and control system. Figure 1 is the block diagram of the RADATS hardware; figures 2(a) and 2(b) show the physical layout of the processing system and the operator consoles.

Computer System

The computer system controls the numerous formatting, decoding, and input-output (I/O) operations while accomplishing the mathematical tasks associated with filtering, refraction correction, parallax correction, state-vector update, and closed-loop control of the radar range and angle systems.

The RADATS includes a Hewlett-Packard A900 computer in a distributed intelligence system consisting of a fast central processing unit (CPU) with hardware floating-point processing capability and cache memory. The CPU is linked to I/O processors on each interface channel. The CPU typically carries out 3 million instructions/sec and can process 500,000 floating-point operations/sec. It is configured with 768 kilobytes (expandable to 6 megabytes) of error correcting code memory, with an uninterruptible power supply backup to preserve system integrity during momentary or extended power outages.

The distributed intelligence concept of the computer separates the processing of I/O instructions from that of other types of program instructions. Built-in programs in the I/O processors provide autonomous control of all I/O operations, including chained, multiple, direct memory access (DMA) transfers of incoming and outgoing synchronous data streams. These transfers are performed without interruption of the CPU except at the start and completion of the I/O task and when

new buffers with updated data are linked into the chain. In the RADATS, both card priorities and program priorities are important. Tasks such as measurement data input and formatted data output, which run on fast cycles and which must occur precisely on time, have the highest interface priorities. Maximum achievable DMA transfer rates for the A900 computer I/O system are 3.7 megabytes/sec input and 3.0 megabytes/sec output.

A sealed, 132-megabyte disk system was selected for program and data storage. The disk system is also configured with a built-in 1/4-in. backup cartridge tape drive for software backup and for permanent storage of data recorded during individual mission operations.

Radar system operators communicate with the RADATS by means of computer terminals. The RADATS has an operator terminal and a system terminal. Figures 3(a) and 3(b) show these terminals in operation with typical information being displayed.

External Interface System

The RADATS external interface system accomplishes (1) the generation of system timing strobes from longer duration, master timing pulses output by the time-code generator-translator; (2) buffering and conditioning of I/O radar data streams; (3) regeneration of raw radar azimuth, elevation, and range bits; and (4) monitoring and control of overall system synchronization.

The timing strobes are pulses that control the transfer of synchronous data to and from the pins of the computer I/O cards. Because the data streams are synchronous, all I/O transitions must occur on time, every time. System synchronization is verified at each data transfer by comparing timing signals generated by the computer and the external interface. This assures that the outgoing data streams are in synchronization with epoch time. If the synchronization test fails, the computer initiates a shutdown and restart cycle during which a complete system resynchronization occurs. Resynchronization takes about three frames (150 msec).

Strapping of the time-code generator-translator prevents disruption of the synchronized outputs when incoming IRIG timing is lost or when a shift occurs in the timing data due to external causes. The system provides an alarm and continues to operate on an internal oscillator until the operator initiates a system resynchronization. The RADATS does not resynchronize during normal mission support operations. Resynchronizations can occur when the timing source — NASA landline, AFFTC landline, or AFFTC ultrahigh frequency (UHF) radio — is changed.

Buffering of the incoming and outgoing synchronous data streams is accomplished in several 4-bit external registers connected to a single, parallel, I/O interface card. In this way, three synchronous radar data streams, in separate formats, are simultaneously passed from the computer to the external interface in parallel form and then from the external interface to the modems in serial form. Two continuous, incoming, serial radar data streams are handled in a reverse serial-to-parallel sequence using 4-bit external buffers.

The read and update cycles of the radar are controlled by the RADATS. Exactly in concurrence with the on-time edge of a 20-pulse/sec strobe, a data update cycle

is started in the digital data section of the radar. Range, azimuth, and elevation data are simultaneously sampled from the radar and sent with event and status (E/S) information to the computer. The E/S information consists of information such as on- or off-target, skin or beacon mode, system synchronization status, automatic or aided track, and tracking or acquisition mode.

Time-Code Generator-Translator

The RADATS includes a Datum 9390 time-code generator-translator as the source of timing data. A data patch panel provides IRIG B timing data from the NASA central timing system (through landline) or from the AFFTC timing system (through landline or UHF radio). Timing signals are synchronized to Universal time, formerly known as Greenwich mean time.

The time-code generator-translator uses these source signals to generate "on time" pulses at various pulse rates for different uses in the RADATS. The 10-pulse/sec output identifies the start of each 240-bit IRIG II frame. The 20-pulse/sec output initiates the read cycles used to enter and format new measurement data; the range and angle designate cycles are used to position the range gate and pedestal angle servomechanisms. The 2400-pulse/sec output controls the input and output of the several synchronized data streams. The 100K-pulse/sec outputs are used to generate internal time-synchronized shift pulses. Advance-retard controls are also provided to compensate for propagation delays in the incoming timing signals. In addition, the time-code generator-translator provides parallel outputs containing the current day number, the time of day in seconds, and millisecond time.

External Monitoring and Control System

The RADATS includes a general-purpose instrumentation bus (GPIB) that is used with standard test instruments to measure voltage from a pedestal-mounted inclinometer system. Other uses for this bus are being planned, such as the control of signal generators installed in the receiver section of the radar and at the bore-sight tower.

A separate 8-channel analog input card is also available for recording various analog levels (such as range, azimuth, and elevation error signals) in real time. The analog input card is capable of acquiring up to 55,000 readings/sec with a 12-bit resolution.

SOFTWARE

The RADATS capability is as much a function of the software as the hardware discussed above. The categories of RADATS software in use are (1) utility, (2) real-time, and (3) calibration. All software packages are interactive; the operators have computer terminals that display a menu of choices from which to select. Operator inputs are accommodated with "fill in the blanks" forms for all information items necessary to accomplish a task. All operator inputs are checked for reasonability before execution. The radar system operators were participants in

the specification and evolution of the set of selection menus and operator commands that were implemented in the RADATS software system. The mathematics used in the RADATS software system are described in reference 1.

Utility Software

Utility software includes programs to enter specific channel and frame formats, programs to reduce or compare data, and programs to perform certain geodetic and mathematical computations of a survey nature. Channel and frame formats are stored on disk and are available for recall to set up the radar system or to be modified as conditions require. A typical I/O format might provide one FTD channel in standard TACDAC format, one channel in IRIG II format using raw measurement data, and one channel in IRIG II format using filtered and refraction corrected data. At the same time, the format might specify standard IRIG II formats on each of the two ACQ channels. Such a configuration is named and stored on disk for future use as, for example, IRIG II. An operator can switch to any other stored I/O format by recalling the selection menu and entering the name of that format.

Data reduction and comparison software is used to analyze data that are stored on disk. With the RADATS, approximately 50 hr of data can be stored on the disk system. When the disk files are nearly full, the operator can transfer the data to a cartridge tape system for archival purposes. Hence, stored data in selectable formats can be read back or printed out as required. Time searching for the desired segment is automatic. The data are available in the following formats:

- a. Time-tagged, raw, octal frame formats
- b. Time-tagged, raw data counts with E/S information included
- c. Time-tagged engineering units with E/S information included
- d. Time-tagged delta counts with E/S information included
- e. Time-tagged, delta, engineering units with E/S information included

In the playback mode, the RADATS operator console can replay a mission that is stored on disk. The operator console displays the time, measurement, and status data that are being read back from the disk. The system also transmits the same data on the three output channels in the same format in which they were originally transmitted.

The RADATS utility software includes a geodetic package to permit the operator to carry out various survey computations needed to support the equipment installations, system calibrations, and general survey tasks associated with space positioning systems. Routines are included for converting geodetic coordinates to radar-centered and earth-centered Cartesian form, for Lambert-geodetic conversions, for determination of true forward and reverse angles and slant range between known geodetic points, and for determining geodetic coordinates from angle and slant range measurements from a known point. The geodetic software is described in reference 2.

Real-Time Software

Real-time software is used for data formatting, data decoding, range and angle designate calculations, digital filtering, state-vector calculations, real-time data capture, data playback, and similar functions. This software is also used for offline programs to display and examine data, to perform adjustments to prestored satellite trajectories, to update optical and radiofrequency (RF) refractivity values, and to select specific spheroid-datum references.

Primary Functions. — During each 50-msec frame time, the following functions are accomplished by the RADATS real-time software:

1. Azimuth, elevation, and range are input as raw measurement data together with E/S information to be entered and tested for validity. Conversions from polar to Cartesian coordinates are performed, and both sets of coordinates are updated in the current value table together with the E/S data words.
2. Raw measurement data are filtered using Kalman optimal estimation techniques. The filtered values are updated in the current value table.
3. System synchronization is checked, and a resynchronization cycle is initiated whenever an "out-of-sync" condition is detected.
4. The day and the time of day are input in binary form from the generator-translator; millisecond time is input in binary-coded decimal form.
5. Acquisition input is performed using the usual search, check, and lock modes. The synchronization search is accomplished by the real-time software and is based on the input frame descriptions that are preestablished for each of the two input channels. If synchronization is lost, the system holds the last valid data until synchronization is reestablished. This keeps the antenna at the last designate point until new data become available. Generally, with a normal IRIG II frame format, synchronization is found within 1 sec after data are placed on the line. When the system is in the lock mode, the data contained in the ACQ stream are used to update the current value table.
6. Each of the three FTD output channels is output in accordance with the I/O format selected by the operator. Any parameter in the current value table may be imbedded at any location in the FTD output stream.
7. The imbedded polynomial error code is calculated for each output channel that has a specified error code.
8. Data on both ACQ channels are parallax corrected to provide proper look angles and ranges from the WATR AN/FPS-16 radar. When synchronization is found on either or both ACQ channels, the software decodes the site address. Using matrix rotation and translation parameters stored for each of 127 assigned site addresses, the software system performs the required parallax correction.
9. Systematic errors are corrected, including mislevel, nonorthogonality, droop, encoder nonlinearity, and RF axis shift.

10. Drive signals are generated for pedestal elevation and azimuth angles when designating the antenna. The algorithms that compute the drive commands compare present antenna position with desired antenna position. Software lockouts prevent the antenna from being driven below -3° or above 183° in elevation. The drive algorithms achieve maximum permissible slew rates in both azimuth and elevation while minimizing overshoot conditions.
11. Digital range designate commands are generated for the advanced digital ranging (ADRAN) system. This system receives the information in 20 bit parallel words at a rate of 20 pulses/sec.
12. Refraction corrections are computed using a high-accuracy method that projects the wavefront from the pedestal reflector to the target in transit time increments of about 3 sec. During each incremental projection, the amount of bending is computed using the refraction gradient normal to the direction of the ray travel. The next incremental projection is made from the adjusted plane of the wavefront. The gradient refraction correction can use a vertical profile that is exponentially generated from surface psychrometric data, or it can use actual rawinsonde measurements of the airmass. In the latter case, an exponential extrapolation is used to obtain values between the measurement points, usually provided for each 1000 ft of altitude.
13. The target state vector is updated. This consists of the target position, velocity, and acceleration components of azimuth, elevation, and range.
14. The geometric altitude of the target is computed on each of the refraction correction cycles. Target altitude can be referenced to mean sea level or any local landing surface.
15. Radar data capture is accomplished from any one of the three outgoing FTD channels or either of the two incoming ACQ channels selected for recording on disk.
16. The operator console is updated. This console displays RADATS information in the operator's choice of the many available display formats. It is possible to view normal FTD parameters, parallax-corrected or non-parallax-corrected real-time acquisition data, and computer-generated designate parameters.

Optional Functions. — In addition to the above functions that are performed routinely during each 50-msec data cycle, the operator can select a number of additional programs in real time, as follows:

1. The satellite designate program provides continuous updates (20 updates/sec) of the azimuth, elevation, and range designate data to follow a smooth curve generated from orbital predictions. The program allows for real-time modification of range and angle parameters to permit maximum target return and to adjust the target within the range gate. Lock-ons can be made outside the gate using the multigate feature of the radar. However, a faster lock-on can be achieved if the target is within the gate where a lower signal-

to-noise ratio is required. For this reason, as soon as the target trace becomes slightly visible on the scope, adjustments are made to place it directly into the center of the gate.

2. Nutation routines permit the operator to select nutation modes (for example, circular, horizontal, and box) together with selections of the amount of angular coverage afforded by the various nutation patterns.
3. Engineering units are selected according to operator preference for data display. Range unit selections include raw data counts, feet, yards, meters, statute miles, and nautical miles. Angle unit selections include raw data counts, degrees, mils, and grads. The time of day can be displayed in Universal time or in any one of several local time zones.
4. Psychrometric data are entered using background routines that permit the operator to update these data during mission support operations. These data are entered as wet-bulb temperature, dry-bulb temperature, and atmospheric pressure. After their entry, new values of optical and RF refractivity are computed and stored for the real-time refraction correction routines.

Calibration Software

Calibration software is used to insure the highest levels of accuracy in the data provided to the various user groups. This includes software for both routine and special calibrations involving optical and RF collimation with both "corner" and frequency shift reflectors, beacon packages over first- and second-order survey points, optical targets, star tracks, and inclinometer systems. The various calibration programs and routines are as follows:

1. The star calibration program operates in a background mode and generates continuous pointing information for any of the 1535 stars contained in reference 3. Ephemeris data for all cataloged stars are contained in disk files. When the star program is entered, the operator can specify a calendar date and time for which a list of available stars is desired. Separate entries also allow the selection of a minimum elevation angle and a minimum level of brightness of the stars on the list. After the star list is obtained, the operator can sequentially select any star on the list. When a star number is selected, the computer designates the antenna to that star and tracks it continuously until another star is selected. Angle designate data for the star track are provided at the standard 20-update/sec rate. Displays at the operator console dynamically show the computed azimuth and elevation angles, the encoder readouts of the current azimuth and elevation angles, and the error between the two. Normally, the drive signals hold the antenna on the star trajectory to within one least significant bit value (approximately 0.00275°). After a specific star is selected, the operator may alternate between normal and plunge track modes by simple function key selections on the keyboard.
2. Normal and plunge track modes are operator selectable. When a target is being tracked and reverse track is selected on the operator console,

computer designate commands are furnished to the range and angle systems to slew the antenna to reverse azimuth and elevation for fast target reacquisition. This is useful in determining a true optical aiming point on both aircraft and balloon targets.

3. Manual entry modes are available to allow the operator to input target range, azimuth, and elevation data or target latitude, longitude, and altitude data to position the range and angle systems at a specific point in space. This is useful when verbal acquisition commands are being received from pilots, onboard measurements, or from data plots being used by ground flight controllers. Geodetic inputs can be made in any one of several selectable earth model-datum references.
4. Prestored survey coordinates are provided to allow the operator to select any of 50 coordinate sets stored in the system. When point is selected, range and angle data are generated by the computer to bring the antenna onto that point. This is helpful in bringing the antenna onto various reflectors or targets on the Rogers Dry Lake surface. These targets are used for premission and postmission system validations and other types of system calibrations.
5. Automated pedestal mislevel measurements are made using an electronic inclinometer system. The computer drives the antenna through 360° , stopping at each 22.5° azimuth point. After the inclinometer has stabilized, 20 measurements are taken and averaged. These measurements are taken under computer control with the results displayed on the operator console and printed out on the system line printer.
6. Automated encoder tests drive the pedestal through an operator-selected range of azimuth and elevation values. The computer sequentially drives the pedestal to each encoder location within the ranges specified and determines if the proper encoder readout is obtained. If any location returns an incorrect reading, the reading of that location, together with readings from several adjacent locations, is provided both on the operator console and on a hardcopy printout.

A second test is provided to cause the antenna to slew in angle, thereby sequentially turning on each bit in the encoder electronic system. It also sequentially positions the range gate to values that turn on each of the range bits. An acceptable test point is obtained when only the desired bit is turned on. The test is simultaneously performed on all three channels — range, azimuth, and elevation.

7. An automated board check routine is available for a simultaneous end-to-end check of the radar, all slaved antennas, the WATR control room displays, the long-range optics, and the plotting boards. During this test, the antenna is slowly slewed throughout 360° of azimuth and 90° of elevation. Operators on all the other systems carefully watch for any dropouts, anomalies, or abnormal behavior in the received signals. This check is performed each day as part of the total system preflight testing.

8. Parallax corrections may be tested by looping FTD internally to the two ACQ channels. The site address and measurement data are sequentially output using all the site address codes in the current remote site tables. As the address of a particular site is output, its range, azimuth, and elevation values with respect to the WATR AN/FPS-16 radar are also output. Thus, from the parallax-corrected data observed on the operator console, the target point should lie at or near the horizontal and vertical axes of the AN/FPS-16 radar. This routine tests the synchronization and decoding of each ACQ channel as well as the accuracy of the parallax-correction routines.
9. Additional radar data enhancement software is available for the operator to observe the amount of refraction correction being applied to range and elevation data, to observe the behavior of the Kalman-filtered data, and to observe raw data being received on either ACQ channel. When range calibrations are performed, the use of filtered data stabilizes the range readouts and eliminates the one or two least significant bits of range noise that would otherwise be present.

OPERATIONAL EXPERIENCE

The RADATS performs the tasks that the radar operators require in a simple, straightforward manner. Virtually everything an operator needs for control, display, and data analysis information is conveniently available in a usable form during premission, real-time, and postmission operations. The operator can obtain real-time answers about the effects of adjustments.

System Experience

Target acquisition performance has been greatly enhanced by the RADATS. Operator displays have been structured through experience to be especially clear and readable. The operator can make quick, effective decisions on source selection and radar system configuration. Track validity is enhanced by the delta tracking feature that indicates the difference in space position between the local track and the ACQ source track. The full effect of local systematic errors is included in this computation. The extensive calibration and analysis software built into the RADATS supports the rapid resolution of differences in tracking results between ranges.

If radar data are needed during a mission to specify space position for a mission-related test point, the operator "freezes" the data display to note location and system parameters for the user. This is done without affecting the output data stream.

The RADATS has proved to be a very "solid" system. The RADATS rarely resynchronizes except for operator-selected changes in the acquisition or timing source. The software has matured to become virtually trouble-free. The exceptional hardware reliability experience is attributed to the extensive use of standard off-the-shelf products and buses. The system has never failed to perform during mission support.

The RADATS is probably the most complex implementation of processing, calibration, analysis, and control tools at the WATR tracking site. Nevertheless, of all the systems at the tracking site, this one has been the most quickly mastered by new operators. This is due to the clear and logical implementation of the input menus, operator controls, and data displays designed into the system. The RADATS performed according to specifications when it was first delivered. Operational experience has been used since then to evolve the controls, displays, and analysis tools to become even more useful and easier to operate.

The geodetic software has enhanced acquisition time when the operator knows the target latitude, longitude, and altitude from voice or telemetry information. It has also been valuable in supplying interim survey information for new systems, such as telemetry and communications directional antennas and slaved pedestals for long-range optics.

The RADATS has made the WATR tracking site fully independent of external processing resources. Support provided on request to another range does not require that any other NASA facility be involved to prepare for, accomplish, or analyze a tracking mission.

Project Experience

The space shuttle, a maneuvering orbital vehicle without a radar beacon, has been extensively supported by the RADATS. For this program, the major challenge was to acquire a skin track on the shuttle because of its distance when it first appears on the horizon and because of the uncertainty of its position due to maneuvering on reentry. The orbital software built into the RADATS, with its ability to accept bias information in real time, can compensate for the differences between predicted orbit times and actual time due to target maneuvers. Moreover, the operator-selected nutations applied to the designate data further increase the likelihood of rapid acquisition of a valid track.

Immediately following a shuttle support mission, either an orbital or a landing track summary message must be sent. By using the RADATS readback capability, the radar operator obtains the precise time and position of the target at acquisition of signal (AOS), at the point of closest approach (PCA), and at the loss of signal (LOS). For shuttle landings, the touchdown groundspeed, rollout distance, and final rollout points must also be provided. The readback program is usually operated in a background mode at the system console. Readback is provided while the real-time programs continue to perform all of the various encoding, decoding, and real-time processing functions that are under the control of the radar operator from the operator console. The analysis of RADATS-acquired, radar automatic gain control (AGC) data combined with shuttle flight telemetry makes possible the real-time derivation of radar cross sections from approach and landing flight data.

RADATS flexibility was recently emphasized during a short lead-time requirement on the advanced fighter technology integration (AFTI) project with the F-111 aircraft. The requirement involved the use of USAF Western Test Range tracking data for plotting and the positioning of telemetry and communications antennas on the WATR. A minor software change in the RADATS provided a method to output the incoming ACQ data as parallax-corrected FTD to the local radar site. Control of

the output data selection was determined by a function key on the radar operator terminal. This allowed the mission control processing systems at Ames-Dryden to use the remote information as if it had come from a local WATR track.

CONCLUDING REMARKS

The radar data system called RADATS is reliable, compact, and easy to use, and has the capabilities for processing radar and associated orbital, geodetic, and calibration information in a convenient and timely manner. It has proved to be a useful tool at the NASA Western Aeronautical Test Range radar site for enhancing the space position data product and for optimizing the performance and accuracy of the radar system. Ease of system enhancement to meet new requirements has been demonstrated. The RADATS makes possible the operation of the tracking site in support of a mission without requiring any other processing services or NASA facilities.

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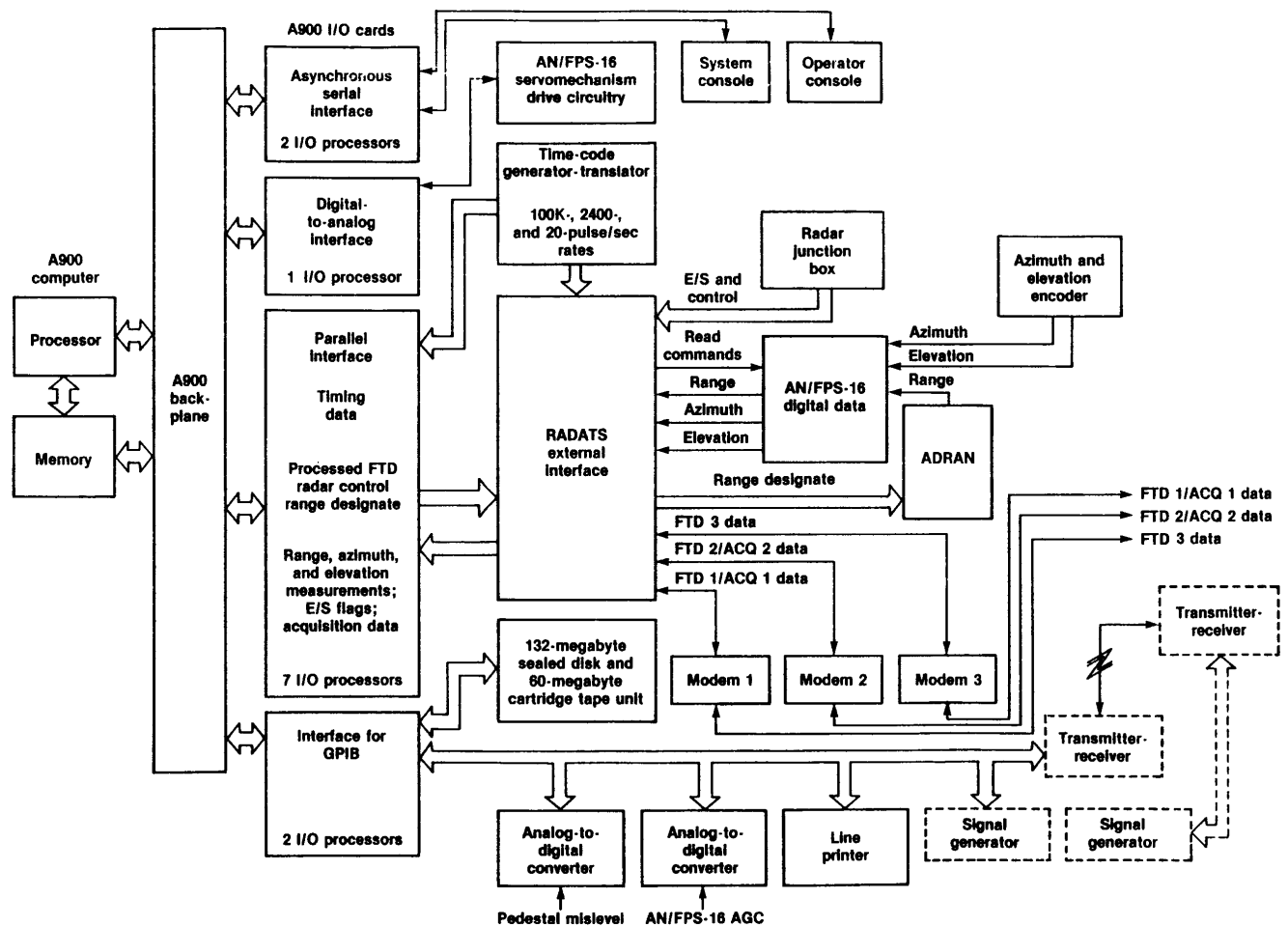
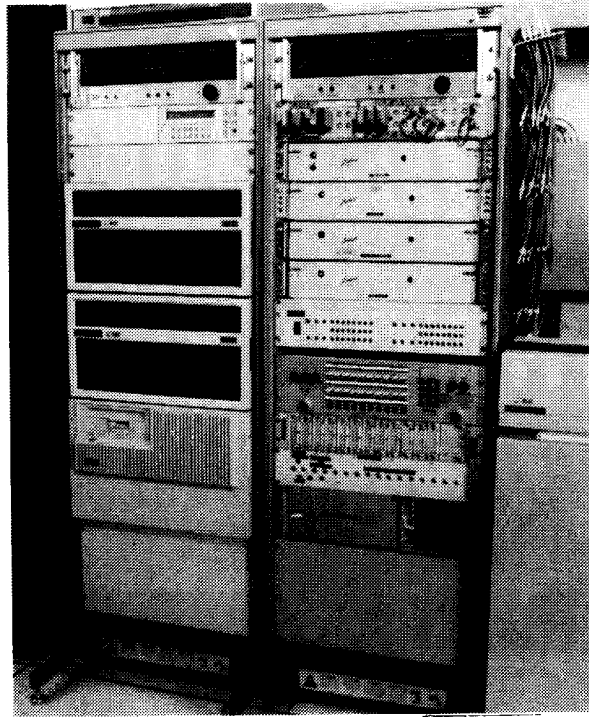


Figure 1. RADATS block diagram.



ECN 33503-004

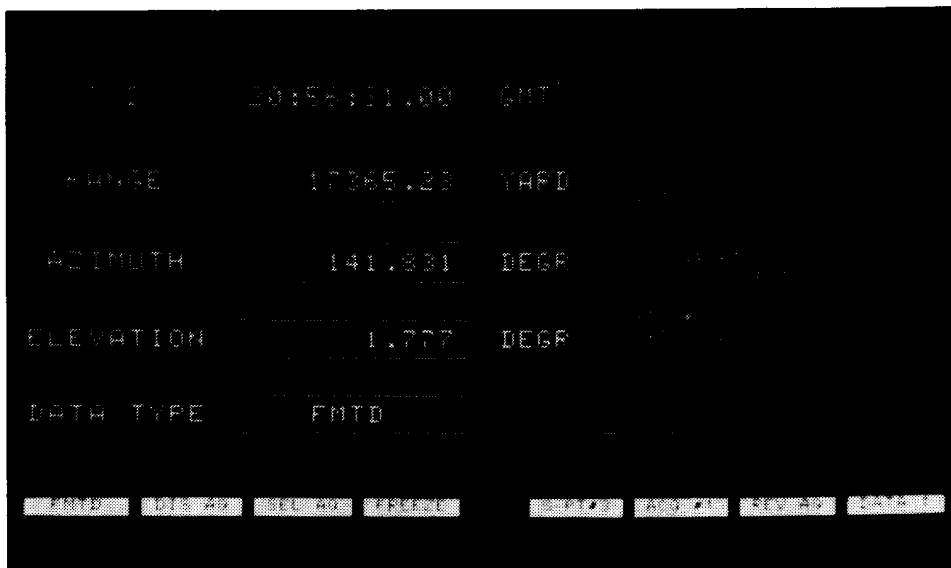
(a) *Processing and interface system.*



ECN 33503-003

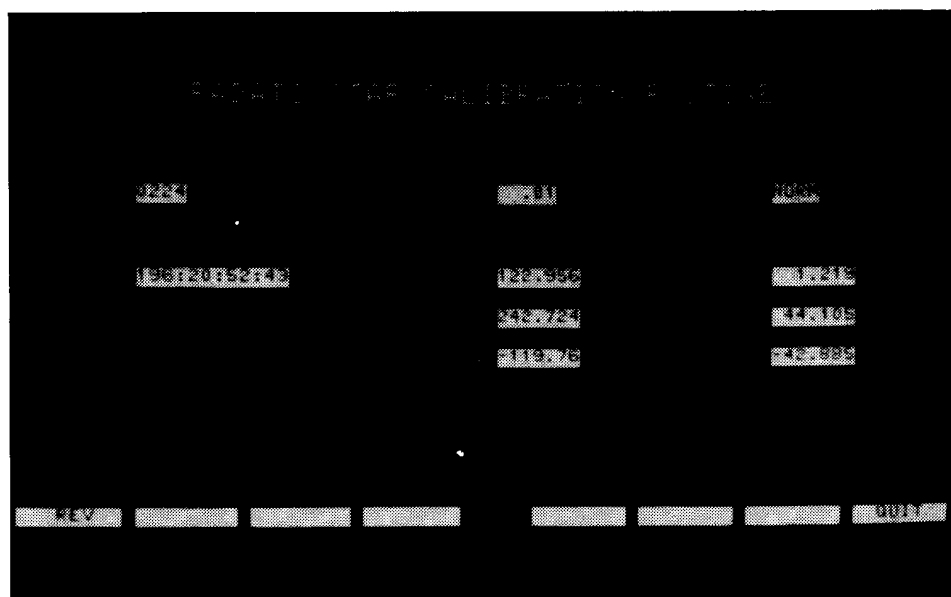
(b) *Operator consoles.*

Figure 2. RADATS in operation.



ECN 33503-001

(a) Formatted tracking data display.



ECN 33503-002

(b) Star calibration data display.

Figure 3. RADATS operator terminal with typical display information.

[illegible]

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